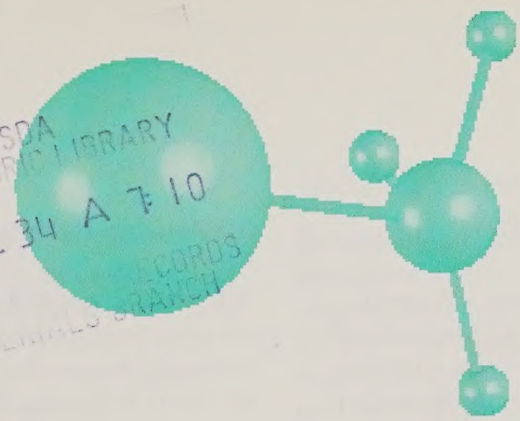
Methyl Bromide *Alternatives*



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Inside This Issue

This issue and all back issues of the *Methyl Bromide Alternatives* newsletter are now available on the Internet at **<http://www.ars.usda.gov/is/np/mba/mebrhp.htm>**.
Visit the ARS methyl bromide research homepage at **<http:/www.ars.usda.gov/ismbmebrweb.htm>**.

This newsletter provides information on research for methyl bromide alternatives from USDA, universities, and industry.

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California Strawberry Industry: On the Learning Curve

"For many California strawberry producers, there is a tremendous feeling of uncertainty right now," says Dave Riggs, president of the California Strawberry Commission. Growers are concerned about how soon alternatives to methyl bromide will become available. They want the time to figure out how to best use any alternatives before they become dependent on them.

"We cannot think that we still have a 6-year time horizon to find an alternative to methyl bromide. You can't deliver an alternative on the deadline [in 2005] without allowing time to resolve regulatory issues and for the farmer to learn how to use it."

Riggs explained that some growers feel like they are caught in a Catch-22. Many alternatives are not yet available for them to experiment with, but they need time to figure out how to use any replacement effectively and efficiently before they can balance their survival as a business on it. Many proposed alternatives have not yet cleared regulatory hurdles, he pointed out. Methyl iodide has only recently started down the registration and manufacturing path. Telone and chloropicrin are registered but still face unresolved regulatory restrictions.

"One compound that is always mentioned by EPA [U.S. Environmental Protection Agency] is Basamid, but it is not registered yet and it is a very tricky compound to apply," he said. Research has shown that Basamid may be efficacious, but it can be highly phytotoxic if not properly applied, and its phytotoxicity varies with climate, soil type, method of application, and other factors. "Only when individual farmers learn to use the compound safely and effectively on a large scale, can it really be considered as a workable alternative," Riggs said.

The California Strawberry Commission and USDA's Agricultural Research Service (ARS) have been cooperating in testing alternatives on field plots with various growers since 1996. During the 1998–99 growing season, ARS helped conduct trials in six growers' fields. In all of the trials, the tested chemicals were applied by conventional shank methods and on five of them through existing drip irrigation.

In terms of combating fungal and other diseases, tests with a combination of Telone and chloropicrin and with chloropicrin by itself brought yields to within 5–15 percent of those with methyl bromide, according to Thomas Trout, one of the ARS scientists overseeing the trials. "That still leaves the problem of weeds, but it is a good start," Trout pointed out.

Adapting Takes Time

Trout agrees farmers will need time to learn how to adapt alternatives. Using Telone and chloropicrin combined or alone instead of methyl bromide will, at the very least, require growers to adapt their schedules because these chemicals require longer delays before treated fields can be planted—as much as 3 to 4 weeks compared to a few days.

"Growers may lose a week or two of harvest at one end or the other of the season with these alternatives, although this will vary widely among growers depending on their location and cultural practices. I think we are at the stage now where we know there will be some problems, which we will continue to try to resolve so alternatives like Telone and chloropicrin remain available," Trout added.

The cooperative testing program receives $100,000 a year from ARS, as well as funds from the commission and the state of California. "This research has given the industry as a whole a better understanding of how our next best alternatives [to methyl bromide] may fit into current farming practices," Riggs said.

While strawberry producers are exploring alternatives, a wholesale changeover for most is not yet feasible, according to Riggs. "Farmers must meet today's payroll in today's competitive environment. They use the best tools available to be productive, efficient, and competitive with other California farmers and farmers in other states, as well as with farmers in Mexico who will be able to continue to use methyl bromide," he explained.

Minimizing Potential Losses

What has Riggs and many producers concerned is the potential economic losses that may come in the years following the first year without methyl bromide unless an effective alternative is already a familiar tool for growers.

"The 1993 National Agricultural Pesticide Impact Assessment Program report noted a potential for a 10-percent loss in strawberry production the first year of production without methyl bromide. The Strawberry Commission data also indicate the potential for cumulative losses of 20 percent the second year and 30 to 40 percent in subsequent years due to the buildup of disease organisms in the soil that are not completely controlled by alternatives," Riggs said. "The NAPIAP report also does not take into consideration catastrophic losses from flare-ups of Verticillium or Phytophthora diseases, which can completely decimate an entire field. This not only increases the risk of farming, it also jeopardizes the ability of the farmer to secure financing."

So far, the cooperative field trials, which in some cases have been as long as 3 years back-to-back in the same plot, have not shown signs of flare-ups of these diseases even when conducted on plots not previously treated with methyl bromide—so there is hope for control.

Riggs does not expect that any one alternative to methyl bromide will enable farmers to make up losses. Rather, he believes that farmers will have to find many 1- to 2-percent improvements that will balance a major loss from not having methyl bromide.

"Farmers will have to make up the losses somewhere in production in order to make a profit, because they can't expect price increases to make up the difference," Riggs said. California strawberries are not only in competition with strawberries from countries where methyl bromide will still be allowed, they are also in competition with other choices like bananas and pineapples."

The problem is really that none of the chemicals being discussed now treat the soil as completely as methyl bromide, according to Frank Westerlund, director of research for the California Strawberry Commission. One of the biggest differences for most of the proposed alternatives is how far these chemicals will move through the soil by themselves. When methyl bromide is applied 12 inches deep in soil, it will penetrate another 1 to 2 feet on its own. Telone moves only 6–12 inches deeper when similarly applied, Westerlund explained, so the soil is not as completely treated.

There is also the possibility of a biological control alternative to be considered, according to Westerlund. "People talk about methyl bromide sterilizing the soil. That isn't the case in strawberry fields where methyl bromide is used either as a stand-alone product or when it's mixed with chloropicrin," he said.

Microorganism populations are simply suppressed for a time and then return slowly rather than the soil being recolonized from the outside. This leads to the possibility that beneficial microorganisms could be injected into the soil to fill the ecological niche, preventing the buildup of damaging fungi and other microbes.

"But could the beneficials outcompete the pathogens in soil that has a full existing population?" Westerlund wonders. "That's an area we need to research under commercial conditions. How biologicals will fit into commercial operations is far from resolved, even in the research environment."

Westerlund added one more point the California Strawberry Commission considers a major concern as the coming methyl bromide reductions increase the demand for alternatives. "We are very skeptical of some aggressively promoted alternatives whose sponsors have not been involved in established research protocols or objective scientific evaluation, or specifically in our controlled studies," he said. "When the next 25-percent reduction comes in 2001, it will substantially increase costs and push more farmers to experiment with novel alternatives. I expect we will see a lot of hype and I don't want to see farmers hurt by methods that are not well substantiated."

Quarantine Use of Methyl Bromide in United States

The amount of methyl bromide used specifically for quarantine work in the United States is a number that is going to become increasingly important in the next few years, since quarantine use is exempt from the coming phaseout. But the number is not as simple to calculate as might be supposed, according to plant pathologist Sally Schneider, who is putting together a report on methyl bromide use in quarantine for the Agricultural Research Service.

"If the U.S. is going to have enough methyl bromide for import and export during the phaseout and afterward, we need a pretty solid idea of how much is being used now for those purposes," Schneider says. "If manufacturers don't have a good idea of how much methyl bromide is needed for quarantine use, how will they know how much they will be allowed to manufacture?"

Historically, there has been no requirement in the United States for separate, detailed recordkeeping of how much methyl bromide is used for quarantine, explained Schneider, which is one reason why coming up with a total is complicated. Methyl bromide is also used in different circumstances in quarantine work: on imports, exports, and in some intra- and interstate shipping of commodities, particularly citrus.

Schneider is still gathering data for the report, particularly about export use. She has been collecting information from commodity groups; shippers and packers; federal, state, and county agencies; and as many other sources as she can identify. "And I would welcome information from anyone else," she adds.

On the import side alone, methyl bromide is used as a preventive treatment on specific commodities where required by regulation to prevent the entry of a pest from a particular country; it is used where a pest has been found in a specific shipment even when there is no country-by-country requirement; and it is used to fumigate nonagricultural imports if pests are suspected of being present in pallets, shipping material, or equipment.

But calculating the comprehensive amount of methyl bromide used on imports has been less involved because one agency—USDA's Animal and Plant Health Inspection Service (APHIS)—monitors compliance with quarantine regulations on agricultural commodities and suspicion of pest infestation in other imports. The agency also maintains a database of fumigant use, Schneider explains.

Import

In 1996, APHIS recorded a total of 402,465 pounds of methyl bromide used on imports, of which 49 percent was used on fruit imports, mainly grapes from Chile. Other fruit imports from Chile included kiwis, peaches, nectarines, lemons, and plums. Cotton was second on the list with 22 percent of methyl bromide use, and vegetables third with 9 percent. Almost 17,000 pounds of methyl bromide were recorded as being used on imports where wood borers were suspected or spotted, mostly in packing material.

Total import use of methyl bromide in 1997 was 357,193 pounds according to APHIS, with 58 percent used on fruit, again mainly from Chile, 11 percent on vegetables, 10 percent on cotton, and 6 percent on imports that could be harboring Khapra beetle. In 1998, the total was 281,274 pounds of methyl bromide with 62 percent used on fruit, 14 percent on vegetables, 6 percent for wood borer, and 5 percent on Khapra beetle.

"Obviously, the amount of methyl bromide used on imports changes each year based on pest outbreaks, discovery of new pests, and new

trading partners. Agricultural imports vary each year due to many factors including the quality and yield of a crop at home and abroad," Schneider says. "All of these factors affect the amount of methyl bromide needed each year, but we can get an idea of the average amount being used."

Export

Determining the amount of methyl bromide used to fumigate exports is much more difficult because no one agency keeps general records, and there are no definitive standards for what information should be kept.

For example, in California, it is the county agricultural commissioners who certify fumigation chambers and record methyl bromide use. "Some keep the data by commodity and destination; some keep track only of the amount used, but not by commodity or destination," Schneider says. "Information on commodity and destination is necessary to determine if the fumigation was a required quarantine treatment covered by the exemption or a nonquarantine precautionary treatment." In the Pacific Northwest, much of Schneider's information is coming from the commodity groups because most fumigation is on apples, cherries, and stonefruit.

Another factor that makes it hard to project average use on exports is that some record sources refer only to the pounds of a commodity that had to be treated to meet the receiving countries' quarantine regulations. This doesn't translate directly into the amount of methyl bromide used, since the amount needed to achieve the required concentration depends on the size of the fumigation chamber and not whether the chamber is completely full or half empty.

"Really, the question is how many times was the fumigation chamber used, not simply how many tons of fumigated fruit were shipped each month," Schneider explains. Ballpark estimates on the amount of methyl bromide used for export quarantine treatment of fruit and nuts are 143,000 pounds in 1996, 175,000 pounds in 1997, and 137,000 pounds in 1998. Oak logs are a significant export user of methyl bromide for quarantine purposes, but data on the amount used each year is still being gathered. So Schneider is piecing together a widely spread picture of methyl bromide fumigation on exports.

One surprise that she has run into is that methyl bromide for fumigating dunnage—pallets and other packing materials used to crate exported products—may end up proving to be a much larger percentage of quarantine use than suspected. "All those pallets and skids that are made of wood can harbor insect pests that are of concern to our trading partners, so a lot of it ends up needing fumigation," she explains. Information from one port alone, indicated that more than 45,000 pounds of methyl bromide per year was used to fumigate dunnage.

With data still accumulating, Schneider is not ready to put even preliminary numbers on total export use. But she expects to have a draft report "with a pretty good handle on the amount" ready this summer.

Interstate and Intrastate

The third category of methyl bromide use in the United States is for federal domestic quarantines, state exterior quarantines, and state interior quarantines, which affect interstate and intrastate shipping of some commodities. Gypsy moths on trees, shrubs, and mobile homes are subject to federal domestic quarantine. Exterior pests on citrus and blueberry maggot on fresh blueberries can be treated with methyl bromide to meet California exterior quarantine requirements. Mediterranean fruit fly is an example of a pest that is subject to within-state quarantine in California.

"It can be hard to put together all the numbers to get a complete picture of methyl bromide use in this category because there are different agencies in each state keeping track, and each one is keeping the information in a different way," Schneider says.

Is This So Important?

Methyl bromide, or effective alternatives, is an essential part of the quarantine process that allows international agricultural trade, Schneider points out. "One of the standards on which the free flow of agricultural trade depends is the assurance that nonnative pests can be prevented from entering a country along with commodities and other imports. The United States must be able to prevent the introduction of foreign pests that would threaten the security of U.S. agriculture. And other countries want to be sure that what the United States is shipping is free from threatening pests," she explains.

The United States certainly cannot do without agricultural trade, Schneider adds. Not only are agricultural commodities a major export for the United States, but U.S. consumers have come to expect and depend on the year-

round availability of fresh fruits and vegetables. To maintain such abundance requires that agricultural commodities continue to be importable, but without creating a risk of allowing in new pest problems that could threaten the country's crops and landscape plants.

"There is also the possibility, if not the probability, that new insect invaders will emerge in the future that will require fumigation of commodities. How do we estimate the amount of methyl bromide needed to meet new pest problems?" Schneider asks.

Right now, methyl bromide is the fumigation method of choice for many commodities, Schneider says. But there are potential alternatives, and research is continuing to pursue the possibility of still others. "Irradiation, controlled atmospheres, temperature treatments, other chemicals—there are a number of alternatives being looked at," she says. "Even if quarantine use is currently exempt from the phaseout, we don't want all of our eggs in one basket. It would be nice to have other choices if we need them. A change in the Clean Air Act gave us the quarantine exemption. Another change could revoke it. We need to continue our research to develop viable alternatives."

On Methyl Bromide's Turf

The next person who wins the Masters at eight under par like Jose Maria Olazabal did this year may want to thank the researchers looking for an alternative to methyl bromide for the turf industry.

Right now, the turf industry depends on methyl bromide in golf course and athletic field construction and renovation, from the historic Augusta National Golf Club, where the Masters is played, to neighborhood Little League fields. Turfgrasses are also principal vegetative covers for sites such as airports, parks, roadsides, cemeteries, and commercial buildings. In Georgia, there are an estimated 1.6 million acres in turfgrass. More than 53,050 acres in Florida are used for producing turfgrass sod, with a farmgate value of $499 million.

While there is no methyl bromide alternative right on the horizon for turf use, University of Florida Extension Turf Grass Specialist J. Bryan Unruh, who is in his second year of trials, has hopes of coming up with workable treatments.

"With turfgrass, we are dealing with some different issues because we are working with a perennial crop rather than an annual crop," Unruh explained. "We really depend on methyl bromide when we establish new fields."

In turfgrass, methyl bromide's primary use is to eradicate weeds and undesirable grasses such as nutsedge and common and off-type Bermudagrass, although some nematode and disease control is also expected. Fields, especially putting greens, are expected to have a uniform surface and texture. To achieve that consistency requires the removal of all weeds prior to establishing a new grass, along with any grasses not of the planned variety. Currently, before certified planting material is planted on a field, it is treated with methyl bromide either by a hot gas or solid tarp method.

In the solid tarp method, liquid methyl bromide is injected into the soil at a depth of 8–12 inches, and then the area is immediately covered with a polyethylene tarp to retard the dissipation. In hot gas applications, a thin polyethylene drip tape in laid under a plastic tarp. Liquid methyl bromide is heated to produce a gas that diffuses into the soil. In both methods, the tarp is removed after a minimum of 48 hours and the soil is aired for at least 3 days before planting.

Unruh, and colleagues Barry Brekek and Joan Ducky, are testing 12 different treatments as possible alternatives, including dazomet, chloropicrin, metam sodium, methyl iodide, two "numbered" compounds, combinations of some of these chemicals, and some in combination with tarping.

"To our knowledge, we have the only large-plot trial looking at methyl iodide," Unruh said. "And with a 1,500-square-foot plot, it is a very expensive treatment right now; at our experimental rate, it would cost $6,000 to treat an acre. Of course, if this proves to be a viable alternative, presumably the cost would go down."

He is in the midst of analyzing the data from his first set of trials, which included three test sites—one in south Florida near Punta Gorda, one at the West Florida Research and Education Center in Jay, and one north of Savannah, Georgia.

"We have seen some differences between treatments. Tarped metam sodium co-applied with chloropicrin, seems to show some promise, although without the tarp, the combination was ineffective," Unruh said. However, he does not

expect there will be a one-for-one replacement for methyl bromide. “And we’re certainly not likely to find anything with the same ease of handling and human safety,” he added.

Unruh is also looking at the possibility of using high-nitrogen organics like bone meal and blood meal as alternatives to methyl bromide. He is currently running greenhouse studies primarily to look at weed control. This year, he is testing 0.5, 1, 2, and 4 percent by weight high-nitrogen organics in a variety of soil types.

One advantage of using high-nitrogen organics is that they are also a source of fertility for the grass, he pointed out, which cuts down on the amount of other nitrogen fertilizer needed.

Unruh’s work is being supported by the University of Florida, the Golf Course Superintendents of America, and Hendrix and Dail, Inc., a major soil fumigation company that serves the eastern United States.

In the long term, finding a workable alternative to methyl bromide is really going to be essential for several segments of the turf industry, explained Steve Godbehere, research director at Hendrix and Dail. “Buyers expect certified planting material to be clean of any contaminants, so producers really need an alternative,” he said.

Once common Bermudagrass gets established, the stolons are very deep rooted and even multiple applications of herbicide will not kill it, making it a nightmare for those responsible for a smooth, consistent putting green surface.

And before golf course superintendents can change varieties to take advantage of new disease resistance and drought tolerance, they need to be able to eliminate existing stands. Right now, methyl bromide is the only viable choice, he explained. “There are alternatives that will take care of broadleaf weeds, but even Roundup doesn’t do the job on perennial and annual grasses,” Godbehere said.

In the short term, turf producers are suffering because of the price increases in methyl bromide as production cutbacks have come on line, he added. Already, fumigation costs have risen about 20–25 percent, according to Godbehere. “And growers are having to absorb it because they just can’t pass the increase along to the consumer,” he said. “The 50-percent reduction in 2001 will be a killer for the turf industry.”

Godbehere would like the U.S. Department of Agriculture (USDA) to consider funding more research that looks for a methyl bromide alternative for turfgrasses. “I’m not sure USDA understands how big the turf industry really is and how badly it needs an alternative,” he said.

Plant geneticist Wayne W. Hanna, who develops new turfgrass varieties at USDA’s Agricultural Research Service, Forage and Turf Research Unit in Tifton, Georgia, is looking at developing cultivars that are more competitive with weeds. Although not specifically because of the impending loss of methyl bromide, one of Hanna’s goals is developing turfgrasses that need fewer inputs, including pesticides.

“One of the traits we rate for as we develop new varieties is the ability to naturally crowd out weeds, and we do see great difference between grasses in the research plots,” he said. Hanna also sees the possibility of genetic resistance to nematodes. But, while more competitive varieties are on the horizon, they are at least 3 to 5 years away, and they will not, by themselves, eliminate the need for methyl bromide or an equivalently effective alternative, Hanna said.

Annual International MeBr Conference in San Diego, CA November 3–5, 1999

The fourth Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reduction, will be held November 3–5 at the DoubleTree San Diego Mission Valley Hotel in San Diego, California. Focus of the 1999 conference will be enhancing technology transfer processes and incentive programs needed to implement alternatives, and discussion of implementation problems associated with potential alternatives.

The conference is sponsored by the U.S. Department of Agriculture, the Crop Protection Coalition, and the U.S. Environmental Protection Agency.

The conference will feature concurrent sessions concerning research on alternatives to methyl bromide for preplant, postharvest, and structural uses. Again this year, there will be “focused discussion” presentations and a discussion period at the end of each session. The United Nations Environment Program will also be providing support for a focused

session on international issues concerning alternatives to methyl bromide in developing countries. Individuals wishing to make an oral or poster presentation (one per person) must submit a request form by August 6, 1999. On receipt of a request form, Methyl Bromide Alternatives Outreach will forward information on conference presentation procedures, including instructions on the required two-page written summary and other particulars.

Conference participants must make their own hotel reservations at the DoubleTree San Diego Mission Valley Hotel in San Diego; phone 619–297–5466 or 800–222–8733. A reduced rate will be available.

Objectives of the conference are to

- Enhance scientific information and data exchange on methyl bromide alternatives research
- Provide a forum for exchange of interdisciplinary scientific and agricultural information
- Develop and distribute conference proceedings as a state-of-the-art source of methyl bromide alternatives for researchers, users of methyl bromide, legislators, government policy officials, and the general public
- Support data gathering on potential alternatives to methyl bromide for future evaluation and prioritization
- Monitor development of viable alternatives to methyl bromide
- Evaluate technology transfer processes and incentive programs needed to implement alternatives.

For forms and more information, contact Anna Williams, Methyl Bromide Alternatives Outreach, 144 W. Peace River Dr., Fresno, CA 93711, phone 209–447–2127, fax 209–436–0692; e-mail: annawill@agrc.cnchost.com.

You may register on the web at http://www.epa.gov/ozone/mbr/altmet99.html

Technical Reports

Reducing Methyl Bromide Emissions with a Sheet Containing Titanium Dioxide

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Restrictions on methyl bromide usage have led to an intensive search for improved technologies to reduce both dosage and emission from fumigated plots into the atmosphere, while maintaining its effectiveness for disease and weed control. Improved field management practices such as the use of gas-tight films, shallow injection in combination with irrigation, deep injection (ca. 60cm depth), and application of ammonium thiosulfate or a soil bacterium, etc. have been shown to limit methyl bromide emission in several countries. Machinery injection methods can reduce the amount of methyl bromide application and its emission during exposure period. However, such injection techniques are not entirely suitable in Japanese conditions, as fields are generally too small to employ those methods. In addition, agricultural fields and residential areas coexist, and farmers themselves usually apply methyl bromide without depending on special applicators. Soil surface applications such as cold or hot gas methods are currently in vogue.

In previous studies, we found that using a gas-tight film (Orgalloy film, elf atochem) in surface applications considerably reduced emission loss to 7.6% of the applied amount during 7 days of application (1.4% through the film and 6.2% from surrounding soil surface of the treated area). However, emissions were high soon after removing the film, amounting to 33% emission over the entire period. The total emission is thus largely similar to that after using conventional films such as polyethylene. The standard dose of methyl bromide in Japan varies from 15 to 30 g/m^{-2}, which is near threshold level, and it is difficult to dramatically reduce the dosage by using a gas-tight film alone.

The purpose this study is to develop and evaluate a new multilayer sheet for use in surface application of methyl bromide. The sheet consists of three layers: (top to bottom)—an impermeable layer, a photocatalyst layer, and a support layer. We presumed that emission could be reduced significantly if methyl bromide degradation is enhanced by a photocatalyst, although this approach has not necessarily been well documented at this time.

Titanium dioxide (TiO_2) was chosen as a photocatalyst for various reasons. TiO_2 is a photo-semiconductor causing a redox

reaction on the surface with ultraviolet (UV) radiation (<400 nm). It may be easier to understand if it is regarded as the generator of active oxygen, such as superoxide anion (0_2^-) and hydroxide (OH) radicals. TiO_2 helps to degrade methyl bromide to carbon dioxide (CO_2), hydrogen bromide (HBr), and water. In addition to having a strong photocatalytic action, TiO_2 is considered to be environmentally safe.

The top impermeable (to methyl bromide) layer was selected by measuring the UV transmittance. Both EVOH (0.060 mm: low-density polyethylene/ethylene-vinyl alcohol co-polymer/low-density polyethylene) and fluorinated polymer films (0.050 mm) are excellent with respect to barrier properties and UV-transmittance but EVOH was chosen because of the ease of heat-sealing this material.

A non-woven high-density polyethylene fiber sheet (Tyvek, DuPont) was chosen as a support layer of TiO_2. Tyvek has near 100% reflectivity due to diffuse reflection by polyethylene ultra fine fiber, and good gas permeability.

The TiO_2 photocatalyst (ST–01, Ishihara Sangyo Kaisha Ltd.) was suspended in the solvent, spread ca. 3 g/m^2 on Tyvek sheet, and then heat-sealed with a barrier film. After placing the sheet in the center of a separable chamber (effective irradiation diameter: 10 cm, the upper and lower chamber volumes ca. 400 ml and ca. 280 ml, respectively), distilled water (1 ml) and methyl bromide (2.5ml) were introduced into the lower chamber. Irradiation was performed with a 500-W Xe arc lamp approximated to AM 1.5 G at room temperature. Two detectors were used for measuring gas concentrations: a Brüel & Kjœr 1301 FT-IR-photoacoustic spectrometer to measure methyl bromide, carbon dioxide, and water vapor, and a gas chromatograph for methyl bromide.

Methyl bromide concentrations at the beginning of the test were about 6000 ppm, which decreased to a few ppm within 48 hours after irradiation. Degradation products of methyl bromide were identified as CO_2 and HBr. As generated HBr was neutralized immediately by the soil in field conditions, most methyl bromide recovered in the field at the end of the experiment was near the soil surface and the sheet.

However, the ability of the multi-layer sheet to decompose methyl bromide decreased with repeated use (up to 5 times) because of detachment of TiO_2. It was possible to prevent the detachment of TiO_2 by mixing it with ca. 10% polytetra-fluoroethylene fine particles as a binder.

Although decomposition and removal rates of methyl bromide are slow and dependent on solar radiation, methyl bromide concentrations below the sheet declined rapidly while the sheet was covering the field (7 or 9 days). Just before the removal of the sheet, methyl bromide concentrations between the sheet and soil surface decreased to a few ppm with the multi-layer sheet, as opposed to 1,000 ppm with a gas-tight film.

Our experiments also showed that methyl bromide emission was reduced to less than 1% of the applied amount by using the sheet containing TiO_2, against about 57% and 33% with polyethylene (0.05 mm thickness in traditional method) and gas-tight film, respectively. Moreover, methyl bromide concentrations below the multi-layer sheet and gas-tight film were largely similar until the middle of the fumigation period. This indicates that under field conditions, the use of multi-layer sheet may not greatly reduce the efficacy of methyl bromide fumigation.

The multi-layer sheet can be used easily and repeatedly without any major modifications in current practice of soil surface application. Further, the problem in disposing of the sheet is minimal. We, therefore, believe that the technique is useful for substantially reducing methyl bromide emissions and that multi-layer sheet containing TiO_2 holds promise for commercial use. At the same time, we must study ways to improve methods of application of various chemical alternatives to methyl bromide.

The studies reported here form part of a research project sponsored by the Environmental Agency of Japan.

Application of Methyl Bromide Alternative Fumigants by Drip Irrigation Systems for Strawberry Production in California

Husein Ajwa and Tom Trout,
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The most likely alternatives to methyl bromide in the short term are alternative fumigants [e.g., 1,3–dichloropropene (1,3–D), chloropicrin (CP), and methyl isothiocyanate (MITC)]. Although these fumigants are not ozone depleters, they are potentially

hazardous to the environment and humans if not properly applied. Water-soluble formulations of these alternatives can be applied with irrigation water through the same irrigation systems that are later used to irrigate the crops. The amount of water used to apply the fumigants, application rates, and soil conditions determine the success of these fumigants in controlling soil pathogens and weeds in the strawberry beds. The objectives of our research are to develop application methods for alternative fumigants based on drip irrigation systems and to maximize efficacy and minimize human and environmental risks.

This research has been conducted at two strawberry field sites located in Salinas (USDA–ARS Spence Farm) and Watsonville (Monterey Bay Academy), CA, for the last three years (1996–98). Preplant treatments with the soil fumigants [Telone C35 EC (58% 1,3–D plus 32% CP), chloropicrin EC (93% chloropicrin), and Vapam (42% sodium methyldithiocarbamate)] were drip-applied in early October of each year approximately four weeks before planting. Variables that are being evaluated include amount of water used to apply the fumigants (15, 25, or 35 mm); application rates (manufacturer recommended rate and 60% of that rate); application of combinations of fumigants; and number of drip lines. The fumigants were applied through two drip lines in 76 cm wide beds (132 cm center-to-center) covered with green polyethylene film. In addition to the drip-applied fumigants, MeBr/CP (67% MeBr, 33% CP) at 475 kg/ha and Telone C35 (61% 1,3 D, 35% CP) at 355 l/ha were shank injected with two chisels into the bed at a 30 cm depth. The soil gas concentration of 1,3–D, CP, and MITC in the middle and at the edge of the raised beds were monitored for two weeks beginning 24 hours following application.

Strawberry variety Selva was planted at 30-cm spacing in early November. Yields were collected at least once a week during the production season (April to September). Disease rating and yield from the drip-fumigated beds were compared to yields from non-fumigated beds and from beds fumigated with MeBr/CP and Telone C35 by shank injection.

Monitoring the fumigant concentrations in the soil gas showed that a minimum of 25 mm of irrigation water is needed to deliver the chemicals to the edge of the raised bed using two drip lines. The optimum distribution uniformity of fumigants across the bed was obtained with 25 mm of irrigation water using four drip lines per bed and with 35 mm of irrigation water using two drip lines. The concentrations of 1,3–D and CP in the soil gas were greatest 24 to 36 hours following application. The decline in concentrations of these fumigants in the drip-applied treatments was slower than that in the shank-injected treatments. However, no detectable amounts of fumigants were found in any of the treated soils 14 days following application.

At both sites, bed shank injection with Telone C35 at 355 l/ha (38 gal/a) produced strawberry yields equivalent to those produced by shank fumigation with MeBr/CP. The highest yield (110% relative to MeBr/CP) was in the drip-applied Telone C35 EC treatment at 390 L/ha in 35 mm of irrigation water. Yields from beds treated with the same application rate of Telone C35 EC applied in less amounts of irrigation water (25 or 15 mm water) were, in general, lower than yields from the MeBr/CP treatment.

For all of the alternative fumigants tested, strawberry yields significantly increased relative to the nonfumigated treatment. At the Watsonville site, *Verticillium dahliae* was a major problem that resulted in a substantial yield reduction in the untreated plots (28 to 50% relative to MeBr/CP). Reduced rates of drip-applied Telone C35 EC (235 l/ha) or Chloropicrin EC (135 l/ha) alone or in combination with Vapam did not control *V. dahliae* or *Pythium* spp in this soil. Yields from the Vapam treated beds were lower than yields from the Telone C35 EC treatments and ranged between 67 to 79% relative to MeBr/CP treatment. At the Salinas site, the highest yields were also in the drip-applied Telone C35 EC. However, this site has low populations of *V. dahliae*, and yields from the nonfumigated beds were 91% relative to yields from the MeBr/PC beds.

Weed control by the drip applied fumigants was not evaluated during the first two years. Results from the 1998 trials showed multiple applications of Telone C35 EC through drip irrigation tremendously reduced weed germination, and weed counts in all of the Telone C35 EC treatments were much lower than those in the MeBr/CP or Telone C35 shank injection treatments.

Application of Telone C35 EC through drip irrigation systems to strawberry beds shows promise in controlling soil pathogens and weeds and producing strawberry yields nearly comparable to

present production with MeBr/CP. This application method can reduce costs since separate application equipment is not required. It is expected to be safer than present methods of shank injection since laborers are not required to be in the field during application. It will require good irrigation systems and dependable injection equipment. We expect that emissions from drip application will be lower than with shank application.

Our research will continue to determine optimum drip application rates (minimum rate for consistent efficacy) and conditions (soil water content and amount of water carrier) for all three fumigants alone and in combination to control pathogens and weeds for strawberry production in various areas in California. Because the loss of MeBr will come before this research is completed, we have, in cooperation with the California Strawberry Commission, begun field tests with drip-applied fumigants on growers' fields. Using our best estimates from the research plots, large trials with drip applied fumigants were started on 5 growers' fields in 1998/99. With these trials, we have an opportunity to verify efficacy under a wide range of soil, climatic, and cultural conditions. We also work with the manufacturers to develop safe, practical field-scale application equipment. Growers have an opportunity to test the methods under their operating conditions, determine how they might have to change their practices with the new fumigants, and determine what problems require further work.

Progress Towards Alternatives to Methyl Bromide Fumigation in Bareroot Forest Nurseries in the United States

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Forest nurseries produce 1.5 billion seedlings each year for planting on National Forests, state and private lands, for reforestation after fire, harvest, or tree mortality. Some seedlings are grown in containers but most are planted in slightly raised seedbeds in the ground, then harvested bareroot. The vast majority of bareroot nurseries fumigate soil with methyl bromide to control soilborne pathogens, weeds, nematodes and insects. Forest nurseries account for less that 3% of the total use of methyl bromide, not huge contributors when looked at from a worldwide agricultural perspective, but nonetheless relied upon by hundreds of nurserymen and foresters.

This article reviews the results of USDA–Forest Service research and field trials evaluating alternatives to methyl bromide in forest nurseries. Since 1993, the USDA–Forest Service, Forest Health Protection, Special Technology Development Program has contributed $1.2 million to the search for alternatives to methyl bromide in forest nurseries. The nurseries (both state and federal) have contributed over $800,000 for a total investment of $2 million over 6 years. In addition, the Forest Service Forest Experiment Stations (Southern and North Central) appropriated over $2 million from 1995–99.

Eighteen nurseries throughout the United States have participated including: three in California, two in Oregon and Idaho, and one each in: Washington, Nebraska, Minnesota, Michigan, Wisconsin, Alabama, South Carolina, North Carolina, Georgia, Mississippi and Florida. This project represents the work of more than 42 cooperators. Progress from the South, North Central and Western States follows.

Alternatives to fumigation in the Southern United States

Nurseries in the South grow over 1.2 billion seedlings annually, 79% of the seedlings cultivated in the United States. Michelle Cram, USDA–Forest Service, Forest Health Protection, Stephen Fraedrich and Dave Dwinell, USDA Forest Service Research scientists stationed in Athens, Georgia have been working with universities, states, and industry in testing alternatives to methyl bromide for forest nurseries. They tested organic amendments, dazomet, metam sodium, no fumigation, chloropicrin, eptam herbicide and plant growth promoting rhizobacteria at various nurseries.

In the South, slash, loblolly, and longleaf pine are grown in a one

year crop cycle. For methyl bromide treatments, methyl bromide (67%) + chloropicrin (33%) is applied at 350 lb/ac and tarped. This is the rate and formulation used by most forest nurseries throughout the United States.

There has been no significant disease outbreak in any of the studies carried out over the past six years but weeds (particularly nutsedge) have been a persistent problem. In all the trials, seedling quality and quantity in the control (non-fumigated) plots were acceptable.

The results of these trials indicate that fumigation is applied more frequently than necessary for some nurseries. However, information is lacking on the rate at which populations of disease-causing organisms and nematodes rebound in Southern forest nurseries following methyl bromide fumigation. There are few predictive indicators available to nursery managers to determine when fumigation is necessary to avoid seedling losses in any particular field. The long-range goal is to work on predictive indicators and pest models for better pest management at Southern forest nurseries.

The North Central States

In Northern forest nurseries, Jennifer Juzwik, USDA–FS Research, and Raymond Allmaras, USDA–ARS, both in St. Paul, MN, along with 10 cooperators are focusing on improving soil quality as an alternative to fumigation for black walnut and white pine seedlings. From 1994 to 1996, investigations were conducted in five Northern nurseries to examine soil and pathogen status in the nurseries and to identify operational practices that could be changed to prevent root disease and minimize fumigation. Alternative soil management plans were devised, focusing on reducing soil compaction and ensuring that plant residues remain near the soil surface. These plans contain guidelines such as limiting all nursery traffic to areas not planned to be in nursery beds. They also tested and modified equipment for cultural activities such as subsoiling.

Reducing soil compaction improved soil-water relations, preventing environmental conditions conducive to root disease. Maintaining plant debris at the surface prevented deeply buried plant debris (more than 8 inches below the surface) from becoming a reservoir for pathogens. In the past, the upper 8 inches of soil was sterilized by fumigation or solarization, only to be recontaminated from fungal propagules residing 8 to 12 inches below the surface.

Results from their trials show that soil management procedures can be the basis for reduced dependence on fumigation. Nurseries can use tillage to control depth of placement of cover crop residues, and to prevent hardpan creation thereby managing root disease in white pine and black walnut crops.

In 1998, operational-level trials were initiated at nurseries in Minnesota and Wisconsin to test this customized soil management approach in black walnut and white pine without methyl bromide fumigation. Weed and insect management plans are also being tested.

The Western States

Diane Hildebrand, Robert James, Susan Frankel, and Jeri Lyn Harris, USDA Forest Service, Forest Health Protection, are working with Jeff Stone at the Dept. of Plant Pathology, Oregon State University to identify and implement feasible alternatives to methyl bromide in bareroot forest nurseries in the West. The strategy is to decrease pathogen populations by: (1) reducing the food source for pathogens by replacing cover cropping with bare fallowing; (2) promoting growth of competitive or antagonistic microbes resident in nursery soils through soil amendments with high carbon to nitrogen ratio or biological agents; and (3) reducing seedling exposure to infection through alternative sowing and mulching techniques.

Barefallow, with or without periodic tilling, and the elimination of cover crops was as effective as methyl bromide for controlling Fusarium and weeds at a nursery in central Oregon.

At nurseries in Oregon and Idaho growing Douglas-fir and ponderosa pine, barefallow with sawdust soil amendment has resulted in seedling quality and quantity comparable to fumigation. Results have been similar for repeated trials and are now being tested in a larger scale operational demonstration.

In Idaho nurseries, supplementing barefallowing with additives of potential biocontrol organisms is being evaluated.

At a California nursery, high quality seedlings were initially produced without chemical soil fumigants by forming seedbeds in the fall with a winter mulch covering, followed by early sowing in the spring. However, after a few years, losses became

excessive on several conifer species due to infection with *Macrophomina phaseolina*, a fungus previously successfully controlled by methyl bromide. Current work involves evaluating an alternative chemical (dazomet), fallowing with periodic tilling, and water shade treatment to reduce heat stress. As yet, an acceptable alternative to methyl bromide fumigation is not available for this nursery.

Research priorities for bareroot forest nurseries

Despite progress towards developing alternatives to methyl bromide fumigation, much work remains. Research priorities in forest nurseries include:

1. Strategies for management of specific, difficult-to-control weeds such as nutsedge;
2. Long-term maintenance of adequate soil organic matter levels without cover crops;
3. Fertilization regimes without methyl bromide;
4. Development of pathogen-suppressive soils, for example, with organic amendments which have high carbon to nitrogen ratios and/or biological agents;
5. Improvement of soil pathogen assay techniques and disease prediction models; and
6. Evaluation of soil and environmental factors and how they interact with alternative growing regimes.

Summary

In summary, barefallow, improved soil management, and other cultural treatments can be effective alternatives to fumigation in some nurseries. Biocontrol methods such as rhizosphere bacteria or actinomycetes need further development before they are suitable.

Chemical alternatives to methyl bromide such as chloropicrin and dazomet have been effective at some nurseries. With the use of alternative fumigants, fertilization, irrigation and other nursery operations may need adjustment. Herbicides may also be needed for adequate weed control. However, chemical controls are less desirable because of environmental and human health concerns. Conversion to container production is another alternative for some areas.

Acknowledgment

Editor Retires

Doris Stanley Lowe, who served as editor of the USDA newsletter *Methyl Bromide Alternatives* since its inception, retired from the Agricultural Research Service on June 4, 1999. Her service to the newsletter was very much appreciated.

Ken Vick
ARS, National Program Leader